

GSFC MO&DSD TECHNOLOGY DEVELOPMENT PLAN

TITLE: ONBOARD AUTOMATED ORBIT CONTROL USING FUZZY LOGIC	
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BRIEF TECHNICAL SUMMARY (*Objectives and Approach*)

The Flight Dynamics Division is investigating numerous ways to reduce spacecraft ground operations support costs. The potential for reduction of spacecraft ground operations support costs can be realized by performing selected flight dynamics functions autonomously onboard a satellite.

Performing orbit maintenance autonomously using fuzzy logic control is one of the development projects identified that can provide the first steps toward increased spacecraft autonomy and reduced ground operations support costs. Fuzzy logic is ideal for resolving potentially conflicting constraints that arise when planning orbit maneuvers. Placing the fuzzy logic control onboard for autonomous maneuver computations and execution will significantly reduce the costs and risks associated with ground maneuver planning.

APPROVALS		
WORK AREA MANAGER:	DIVISION MANAGER:	GSFC PROGRAM MANAGER:

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JUSTIFICATION AND BENEFITS

Onboard Orbit Maintenance Using Fuzzy Logic Control

In this era of limited funding and declining budgets, the user community has shown great interest in technology that has the potential of reducing spacecraft ground support operations. There is a trend toward the development of small, highly autonomous spacecraft that are capable of performing many functions onboard. Routine orbit maintenance, maneuver planning, monitoring and evaluation are time-consuming and costly ground operations functions, but not necessarily technically complex. The greatest challenge is in the resolution of simultaneous conflicting constraints; such as resolving a sun constraint, station contact constraints, and thruster firing constraints, with the optimal orbital location of a maneuver. Routine orbit maintenance can be accomplished onboard using proven fuzzy logic control concepts, which are ideal for resolving conflicting constraints. Autonomous orbit maintenance could be incorporated as a companion onboard system to an onboard orbit determination process using GPS, or other methods such as the Onboard Navigation System (ONS). Maneuver computations would be determined onboard using the onboard navigation solution. Maneuver information would be telemetered to the ground for verification. Performing this function on the satellite eliminates the need to perform maneuver planning and evaluation on the ground. This results in more autonomous satellites, and significantly reduced ground operations costs.

APPROACH AND PLAN

A prototype flight software system will be developed that is capable of predicting, planning and calibrating spacecraft orbit maintenance maneuvers. The flight software will be accompanied by a ground system with a GUI for ground testing and verification of the flight software. Both the ground and flight software system will be object-oriented and generic so that they can be used by several missions with little modification. The flight software system is independent of the source of orbit information, and can use GPS, TONS, or any other source of onboard orbit information. The flight software system can interface with other standard spacecraft systems. Telemetry values available onboard, such as spacecraft propulsion system temperature and pressure, will be supplied to the fuzzy logic control engine for maneuver planning and evaluation. Constraints will be defined during the prelaunch phases using fuzzy sets and fuzzy rules and can be changed during flight if necessary. Because the fuzzy control logic is not problem dependent, there is significant reuse from mission to mission. Only the fuzzy sets, fuzzy rules and calculation modules need to be modified to accommodate the maneuver constraints for each mission.

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Task 1 - Geosynchronous Satellite Autonomous Orbit Maintenance

This system will support the UHF-Follow-On 1 (UFO-1) satellite, which is an in-orbit test bed in a supersynchronous orbit. UFO-1 is part of the SAIL (Satellite Artificial Intelligence Laboratory) Program, a joint Navy, Naval Academy, NASA and Air Force project. The SAIL Program provides an environment for development and testing of AI-related software, with the goal to produce viable software that can be used across industry. The UFO-1 satellite is an excellent opportunity for developing tools that may be used by the DoD's UFO fleet of 10 satellites. In addition, because the UFO-1 spacecraft and the next generation TDRSs share the same type of spacecraft bus (Hughes 501) there is the potential for reuse by the TDRS program.

Subtask 1.1 Complete ground-based verification system AutoCon for UFO-1

AutoCon, the ground-based verification system which is currently in a Beta release, will be completed and tested. The AutoCon system, consisting of a computational core and a Windows NT-based GUI, is designed so that the core computation s/w is completely separate from the GUI. This architecture, along with the C++ language, object-oriented design, facilitates both reuse across platforms and conversion to flight software. The first 'release' of the ground software will support geosynchronous satellites, and UFO-1 in particular. After internal testing, the system will be installed at the Naval Academy in the UFO-1 mission operations center, and will be tested against the flight testbed. SAIL Naval Academy personnel will receive minimal training to use the system. The end product is a system that will autonomously plan geosynchronous orbit maintenance maneuvers and display the information graphically.

Task 2 Enhanced Formation Flying with Autonomous Orbit Control

This task will enhance the UFO-1 ground and flight software to support a low earth orbiting ground verification system and the initial flight software design for the Earth Observer -1 (EO-1) mission. The enhanced formation flying algorithms being developed by the FDD for the EO-1 mission will be included in the AutoCon system. EO-1 will be flying in formation with Landsat-7 and possibly EOS-AM1.

Subtask 2.1 Enhance AutoCon to support Low Earth Orbit (LEO) and EO-1 Formation Flying

AutoCon release 1 will be enhanced to support LEO maneuvers and formation flying. Because AutoCon is modular, no modifications to the architecture will be required. Additional calculation

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objects, fuzzy rules and fuzzy sets will be designed, developed and tested. Enhancements include formation flying targeting algorithms, Jacchia-Roberts atmospheric density model, polar plots, maneuver decision and maneuver calibration algorithms. The end product of this subtask will be a ground system, AutoCon 2, which will support LEO as well as geosynchronous orbiting satellites, and will autonomously calculate formation flying maneuvers for EO-1.

Subtask 2.2 AutoCon 2 Flight Code for EO-1

In conjunction with the ground verification system, the design of the flight code will be performed. Mission specific requirements relating to onboard orbit computations, the onboard computer and thruster computations will be defined and used in the design of the flight software. The end product is a flight software design which reuses as much as possible of the AutoCon 2 code and algorithms.

DELIVERABLES

<u>ITEM</u>	<u>DATE</u>
Task 1 - Geosynchronous Satellite Autonomous Orbit Maintenance	
Subtask 1.1 Complete ground-based verification system AutoCon for UFO-1	
a. Complete development of ground AutoCon Release 2.0	6/97
b. Deliver AutoCon Release 2.0 and documentation to Naval Academy SAIL Laboratory	7/97
c. Determine requirements to integrate AutoCon into SAIL's ground system	3/97
d. Integrate and test AutoCon in SAIL ground system with UFO-1 telemetry	8/97
Task 2 - Enhanced Formation Flying with Autonomous Orbit Control	
Subtask 2.1 Enhance AutoCon to support Low Earth Orbit satellites & Formation Flying	
a. Complete requirements and specifications for LEO & formation flying	4/97
b. Complete ground version of AutoCon for LEO formation flying (Rel 3.0)	9/97
Subtask 2.2 AutoCon Flight Code for EO-1	
a. Deliver flight software version of AutoCon for EO-1	12/97

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RESOURCE REQUIREMENTS

<u>Task Name</u>	<u>NASA UPN</u>	<u>FY97</u> (\$K)	<u>FY98</u> (\$K)	<u>FY99</u> (\$K)	<u>FY00</u> (\$K)	<u>FY01</u> (\$K)	<u>FY02</u> (\$K)
Onboard Automated Orbit Control Using Fuzzy Logic	(315-90- 17-04)	100	150	150	150	150	150

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SCHEDULE

ONBOARD AUTOMATED ORBIT CONTROL USING FUZZY LOGIC	FY97				FY98		FY99	FY00	FY01	FY02
	Q1	Q2	Q3	Q4	Q1/2	Q3/4				
<u>1.1 AutoCon Rel 2.0 for UFO-1</u> a. Complete development of ground AutoCon Release 2.0 b. Deliver AutoCon Rel 2 and documentation to Naval Academy's SAIL laboratory c. Determine requirements to integrate AutoCon into SAIL's ground system d. Integrate and test AutoCon in SAIL ground system with UFO-1 telemetry										
<u>2.1 Enhanced AutoCon for LEO & Formation Flying</u> a. Complete reqs & specs for LEO maneuvers and formation flying b. Complete ground version of AutoCon for LEO formation flying (Release 3.0)										
<u>2.2 AutoCon Flight Code for EO-1</u> a. Deliver flight software version of AutoCon for EO-1										
Resources by FY (\$K):	100				150		150	150	150	150